

Triton Burnup Study in JT-60U

T. Nishitani, M. Hoek¹, H. Harano², G.A. Wurden³, R.E. Chrien³, M. Isobe, K. Tobita and
Y. Kusama

*Naka Fusion Research Establishment, Japan Atomic Energy Research Institute,
Naka-machi, Naka-gun, Ibaraki-ken 311-01, JAPAN*

¹Present address: Max-Planck Institute für Plasmaphysik, D-85748 Garching, GERMANY

²Department of Engineering, Univ. of Tokyo, Bunkyo-ku, Tokyo 113, JAPAN

³Los Alamos National Laboratory, New Mexico 87544, USA

1. Introduction

The behavior of 1 MeV tritons produced in the $d(d,p)t$ reaction is important to predict the properties of D-T produced 3.5 MeV alphas because 1 MeV tritons and 3.5 MeV alphas have similar kinematic properties, such as Larmor radius and precession frequency. The confinement and slowing down of the fast tritons were investigated by measuring the 14 MeV and the 2.5 MeV neutron production rates. Here the time resolved triton burnup measurements have been performed using a new type 14 MeV neutron detector based on scintillating fibers[1], as part of a US-Japan tokamak collaboration.

Loss of alpha particles due to toroidal ripple is one of the most important issues to be solved for a fusion reactor such as ITER. We investigated the toroidal ripple effect on the fast triton by analyzing the time history of the 14 MeV emission after NB turn-off.

2. Diagnostics

The detector consists of an array of scintillation fibers embedded in an aluminum matrix coupled to a magnetic resistant photo tube with a high current-capable base. Because the maximum recoil-proton range for a 14 MeV neutron is 2.2 mm in plastic scintillator, we chose to use either 1 mm or 0.5 mm diameter scintillation fiber optics. Because only the neutron coming on the axis of the fiber gives the highest energy deposition in the fiber, this detector has an intrinsic directionality, which has been evaluated to

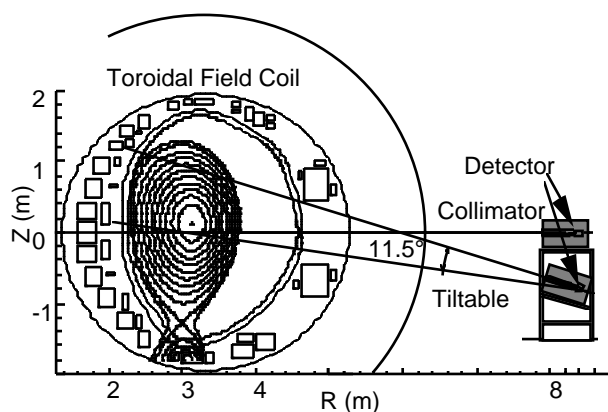


Fig.1 Schematic of sightlines of JT-60U, for the horizontal and tilttable detectors.

be $\pm 30^\circ$. The detector is mounted in a small collimator box, 40 cm \times 61 cm \times 61 cm of borated polyethylene, in order to improve the directionality. The full-width half maximum of the viewing angle with the collimator box was measured to be 15° using a 14 MeV neutron generator.

Two sets of detectors have been installed near the midplane of the vessel, just outside the toroidal field coil position as shown in Fig.1. The scintillating fiber detectors have been calibrated by the shot-integrated 14 MeV neutron yield measured with the neutron activation technique using a pneumatic foil transfer system[2]. The foils are irradiated at 20~30 cm outside of the plasma. The counts of the scintillating fiber detectors and the 14 MeV neutron yield measured with the neutron activation technique have a good linearity in the range of 14 MeV neutron yield 10^{12} - 10^{15} /shot.

Figure 2 shows the typical wave forms of total and 14 MeV neutron emission in the neutral beam (NB) heated discharge. Here total neutron emission is measured with neutron monitors using ^{235}U fission chamber[3]. The scintillating fiber detector system operates in a background of DD neutrons which are ~100 times brighter than the DT neutron signal, at the counting rate up to 100 MHz. The peak DT neutron

rate at the time of neutral beam(NB) turn-off is as high as 2% of the total neutron emission. After NB turn-off, 14 MeV neutron emission decays exponentially with time constant of 435 ms. The total neutron emission decays exponentially with faster time constant of 121 ms just after NB turn-off. After 8.3 s, total and 14 MeV neutron emissions coincide each other, which means that 14 MeV neutron emission is dominant because the neutron monitor is designed to has almost same detection efficiency in the range of energy 5 eV-14 MeV.

3. Time Dependent Analysis

We measured and analyzed the time histories of the 14 MeV emission after turn-off of the 1.5-2 second NB injection. Table 1 shows plasma parameters for three discharges analyzed here, where r_{eff} is an averaged radius weighted by the triton birth profile as

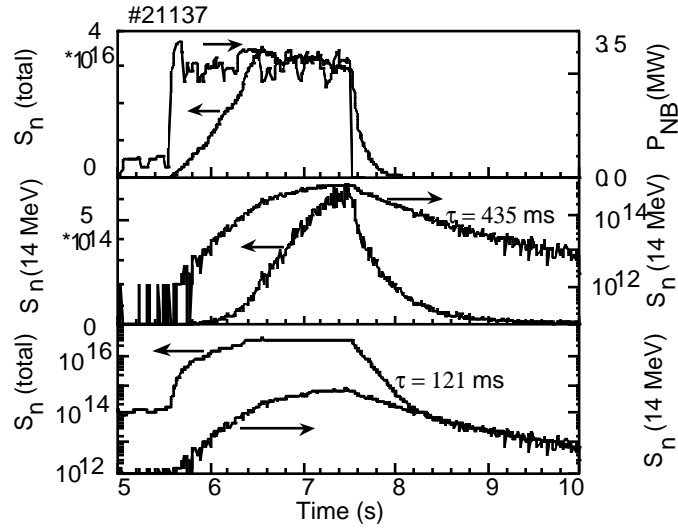


Fig.2 Typical wave forms of total and 14 MeV neutron emissions in the neutral beam heated discharge.

$$r_{eff} = \frac{\int r \cdot 2\pi r F_{triton}(r) dt}{\int 2\pi r F_{triton}(r) dt} \quad (1)$$

where F_{triton} is the triton birth profile calculated by the steady state version of the 1.5D tokamak code TOPICS[4].

Table. 1 Shot list of time dependent analysis

Shot number	21137	23664	23663
Plasma current (MA)	2.2	1.5	1.5
Major radius (m)	3.13	3.19	3.46
Volume (m ³)	49	69	67
q _{eff}	4.5	6.5	5.6
r _{eff} /a	0.36	0.37	0.47
Ripple rate at r _{eff} (%)	0.02	0.06	0.2

The time-dependent 14 MeV neutron emissivity was simulated by a simple classical slowing down model. The plasma was divided into 51 annular shells in the calculation. In each shell, the tritons were divided into 500 groups according to their birth time, with 10 ms time bins. The number of tritons in a group is proportional to the 2.5 MeV neutron emissivity at the birth time of the tritons. Tritons were allowed to slow down in each shell according to the classical energy loss represented by following formula:

$$\left(\frac{dE}{dt}\right)_{classical} = -\frac{\alpha}{\sqrt{E}} - \beta E \quad (2)$$

$$\alpha = 1.81 \times 10^{-13} \ln \Lambda_{ii} A^{1/2} Z^2 \sum_j \frac{n_j Z_j}{A_j}$$

$$\beta = 3.18 \times 10^{-15} \ln \Lambda_{ei} \frac{Z^2}{A} \frac{n_e}{(T_e)^{1.5}}$$

where E is the triton energy, T_e is the electron temperature both in eV, n_e is the electron density in m⁻³ and $\ln \Lambda$ is the Coulomb logarithm. A and Z are the triton mass and charge number; n_j , A_j , and Z_j are the hydrogen and impurity density in m⁻³, mass and charge numbers, respectively. First term of

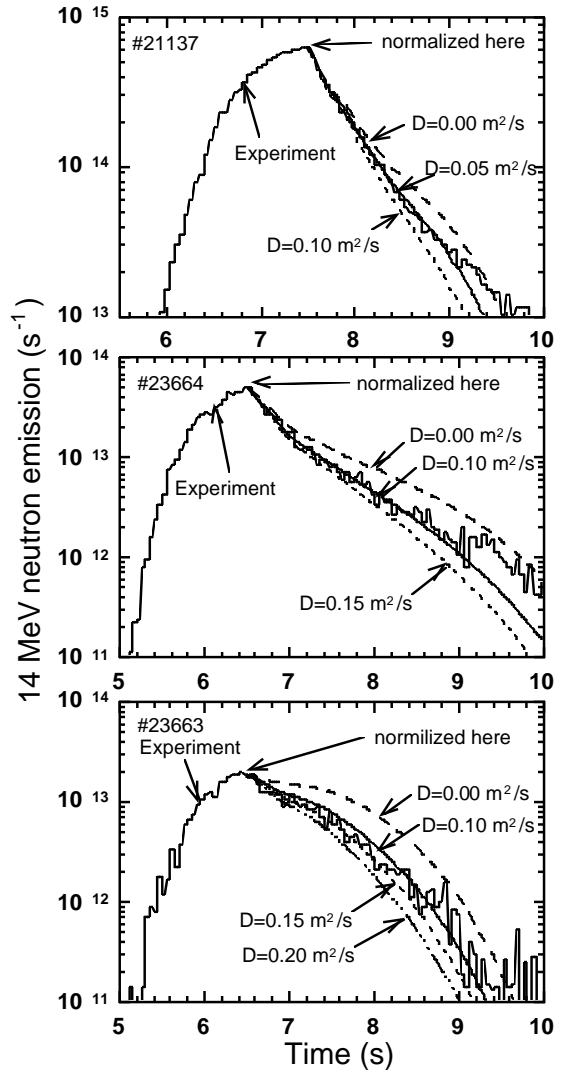


Fig.3 Experimental and calculated 14 MeV neutron emissions for #21137, #23664 and #23663.

R.H.S. of the Eq(1) is the slowing down on electrons and second on is on ions.

The loss of confined tritons was taken into account assuming an exponential decay of the number of tritons of the form $e^{-t/\tau}$ where t and τ are the time since the birth and the confinement time of the tritons, respectively. The diffusivity of fast triton, D_{triton} , was estimated by using the relation for the confinement time $\tau = a_p^2 / 5.8 D_{triton}$ to reproduce the experimental triton burnup ratio. The time history of the 14 MeV neutron emission rate was calculated by using the electron temperature profile from ECE measurement, the ion temperature profile from charge exchange recombination spectroscopy, and the electron density profile from the FIR and CO₂ interferometers as the time dependent plasma parameters. The triton birth profile was calculated using the TOPICS code for a typical time and the shape of the profile was assumed to be constant during the period of the triton burnup. The angular distribution of the tritons was assumed to be isotropic. First orbit losses were taken into account.

Figure 3 shows the experimental and calculated 14 MeV neutron emissions for three discharges listed in Table 1. Calculated curves are normalized to the experimental data at the time of NB turn-off to reject any systematic error of detection efficiencies for the total and 14 MeV neutron emissions. The fast triton diffusivity, D_{triton} , of 0.05, 0.1 and 0.15 m²/s give a good agreement with the experimental data in shot #21137, #23664 and #23663, respectively, which indicate that D_{triton} increases with the toroidal ripple rate as shown in Fig.4.

4. Summary

The time resolved triton burnup measurements have been performed using a new type 14 MeV neutron detector based on scintillating fibers. Time histories of 14 MeV emission after NB turn-off have been analyzed based on the classical slowing down theory. Assuming the loss of fast tritons can be represented as a diffusivity, then values increasing with increasing toroidal ripple were determined between 0.05-0.15 m²/s, from the modeling of the time histories of the 14 MeV emission after the NB turn-off. We have a plan to evaluate the fast triton diffusivity due the toroidal ripple losses using the OFMC code[5].

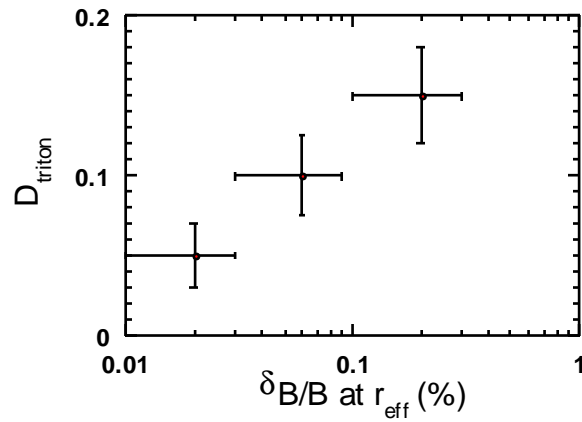


Fig. 4 Fast triton diffusivity plotted against the toroidal ripple rate at the effective minor radius of the triton birth profile.

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